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# HUMAN BODY MODELING AS A HUMAN FACTORS ENGINEERING TOOL

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Computer based human body modeling provides a tool with which human factors issues can be assessed early in a system's design. By populating an interactive visualisation of a design with representative mannequins issues such as fit, reach and vision can be evaluated and design changes recommended at the concept stage. Body modeling tools are continually advancing, offering increasingly sophisticated dynamic representations of the human operator. For the influence of these tools to spread further, they must minimise the demands placed on their users. The user requires a consistent, stable tool which answers the traditional questions of human factors evaluation at an early point in the design cycle.

## INTRODUCTION

The task of the human factors engineer is to match the design of systems to the requirements and capabilities of their human users. Effective equipment design must balance a range of constraints whilst seeking to meet the product's goals. A growing engineering approach has been to use computer aided design (CAD) as a means of testing alternative solutions to the design problem. For usability to be considered during product development it is necessary to represent the capabilities and constraints of a system's human component within this design process. Human body modeling can support this requirement by providing the human factors engineer with a tool that is compatible with the CAD focused design methodologies of product developers.

Virtual reality (VR) now allows dynamic mannequins to be interactively fitted and manipulated within three dimensional models of system concepts. This offers a means of assessing and presenting ergonomic issues at an earlier point in the product lifecycle than previously possible. Identifying and correcting design conflicts at this early stage offers savings in time and money. The process of product design and specification can often be faced with user uncertainty, the instability of user requirements, and a communication gap between the designers and the users. Computer modeling starts to address these problems by allowing user evaluation of the virtual prototype as the basis of defining and refining a common concept of the required system.

There is a widespread perception of VR in which the user puts on a headset to enter an alternate reality. This bears little relation to the current use of body modeling for human factors evaluation. Although many of the tools available will output to a stereo headset, these systems tend to be viewed through a desktop screen. Whilst immersive evaluation of a design promises to be a powerful medium for considering the user's perspective, the benefits of immersion do not, as yet, offset the cost and limitations of its supporting technology. Despite this, the emergence of desktop VR tools has raised the potential for applying novel techniques to human factors evaluation and input to design. Whilst the immersive interface promises another level of model experience, the true value of these environments centres on their ability to visualise and interact with a populated concept model, for which desktop presentation is adequate. Immersive displays do not currently offer an advantage for the core human factors tasks of analysing fit, reach and vision for a given population.

## THE HUMAN MODEL

Modeling the human remains a major challenge to the development of virtual worlds. Whilst inanimate objects such as buildings, machines and landscapes have been convincingly simulated for many years the representation of organic forms, particularly the human, has presented a greater obstacle. The inherent complexity and the absence of uniformity associated with organic forms has made them difficult to simulate both visually and in terms of their behaviour.

Synthetic environments have advanced to provide detailed interactive worlds in which simulated forces can interact over a distributed network. Representation of the human within these environments have tended to either group the human

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within an aggregate force or relegate the user to a simplified component of a more easily simulated entity such as a tank, a plane or a ship.

Recognition of the influence of human behaviour and capability on the real world activities on which synthetic environments have been modelled has led to work to improve the representation of the human.

The Centre for Human Sciences' (CHS) Integrated Performance Modeling Environment (IPME) project seeks to shape the performance of synthetic environment entities based on an integrated set of human performance models. Other work within DERA is looking to incorporate human performance factors within the emerging command agent technology. Great improvements have been made to the visualisation of dismounted infantry within SEs with entity models such as DI-Guy (Boston Dynamics). Whilst the domains of human modeling for SEs and body modeling for workplace analysis are largely separate, they are each working to enhance the human model and may in the future meet in the middle.

The functional complexity of the body model required for workspace assessment depends on the aims of the evaluation. At its most basic, a line of sight assessment could be made by positioning your views of the environment at the operational eye heights for your range of users. Whilst offering an initial assessment, this overlooks the figure's dynamic interaction with the environment such as sitting in a chair or turning to see a display. By using a fully articulated human figure it is possible to make a more complete evaluation of the environment taking into account access, fit, reach, vision, etc. within a system model in a way which relates to the methods and design principles regularly practised in the ergonomic evaluation of hardware prototypes and completed systems.

## COMMERCIAL BODY MODELING TOOLS

A wide range of commercial body modeling tools are available. At the lowest level, it is possible to buy a selection of static mannequins to populate architectural models. Whilst these figures are intended for presentation purposes they might be considered to aid the evaluation of a design by illustrating an area's intended usage. At the other extreme advanced biomechanics models are available which allow the user to develop and analyse musculoskeletal models (Musculographics, Inc.). Between these extremes there are a number of tools which offer dynamic body models for the purpose of design evaluation. An outline of some of these tools is provided in Table 1.

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| Android | (Mechanical Dynamics) A graphical human body model for the ADAMS CAD system. The software enables the user to create human models to study kinematic, static, and dynamic behaviour. |
| COMBIMAN | (CSERIAC) An interactive CAD model offering body size and proportions for Air Force and Army pilots. Provides a tool for reach, strength and vision analyses. Human model is based on a 35 segment representation of the human skeletal system. |
| Crew Chief | (CSERIAC) A derivative of COMBIMAN which provides an interactive CAD model of an aircraft maintenance technician. The model takes into account body size, posture, clothing, strength and vision for evaluating designs for their ease of maintenance. |
| ERGO | (Deneb Robotics, Inc.) A module of the Deneb CAD modeling toolset which offers rapid prototyping of human motion within the work area. The model incorporates forward and inverse kinematics for limb manipulation. |
| JACK | (Transom) Jack is a high fidelity human model which is able to interact with the virtual environment. Features include walking, grasping, eye tracking, animation, collision detection and dynamic strength. The environment provides advanced visualisation features such as lighting and mirrors. |
| Kinemation | (Alias Wavefront) Three dimensional character animation through forward and inverse control of the skeleton. Includes a behavioural model for its skin model linked to time or the skeletal position. |
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| MannequinPRO | (HumanCAD) A development tool to create human mannequins for import to other CAD packages such as AutoCAD. Allows user to create a range of body size characteristic and postures, outputting a static model. |
| MDHMS | (Boeing) The McDonnell Douglas Human Modeling System (MDHMS) is an in-house body modeling tool which includes a three dimensional animated human mannequin. The system provides articulated limbs and inverse kinematics for the simulation of assembly, operations and maintenance. |
| Poser | (Fractal Design) A body modeling tool offering a range of body sizes and body types. Although intended as a visualisation tool, it supports interactive body posture and limb control and allows the output of static CAD models. |
| Safework | (Genicom) A detailed human model whose features include animation, vision analysis, collision detection, and posture analysis leading to a comfort score. The model allows user alteration of critical variables, adjusting the other anthropometric variables based on statistical variations. |
| Sammie | (British Technology Group) A body modeling environment offering anthropometric and morphological control for the analysis of fit, reach, vision and posture. |

**Table 1. Commercial Body Modeling Tools**

### Computer Aided Workplace Design at the CHS

Computer aided design at the CHS started with the acquisition of the Sammie software tool in the late '80s. The Sammie system provided the vehicle ergonomics group with a virtual environment in which an articulated figure could be scaled to represent key anthropometric measurements. The mannequin could then be placed within a skeletal model of a proposed operating environment such as a vehicle crewstation. Figure 1 shows the Sammie mannequin positioned within a concept crewstation which was designed and evaluated by the group using this tool prior to the construction of an experimental crewstation.

After mastering the precise command set and syntax of its UNIX operating system, necessary to run and maintain the software, the user had to overcome a cumbersome interface to manipulate the mannequin within the virtual environment. The system was full of promise, offering a method of viewing and evaluating a concept environment from the perspective of a representative user. However, the time and effort required to set up a populated environment for evaluation reduced the number of occasions on which computer modeling could be justified over paper based techniques and hardware mock-ups.

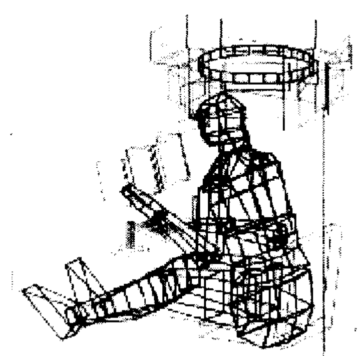

**Figure 1. Sammie Mannequin within a Concept Crewstation Model**

Despite the limitations of the group's early body modeling tools, the recognised potential for improved input to the product design cycle led to their subsequent acquisition of the JACK body modeling tool. Improvements in affordable computing power, JACK's enhanced anthropometric model, its more usable interface and its advanced functionality were considered to counter many of the limitations of earlier systems. Continual improvements to the modeling tool and to the power of its host computer platforms have led to a gradual rise in its application to specific human factors design projects.

The group has explored the extent to which the body modeling tool can be usefully applied. Designs evaluated using this tool include a hand held imaging device, the control panel for a remotely piloted vehicle, office environments, crewstation designs, and a harbour traffic control room.

Figure 2 shows a virtual world generated in the body modeling environment to assess a control room. At one level, design alternatives to the control room were assessed against considerations such as furniture design, inter-operator communication and the position of display screens. In addition, it was important to consider the controllers' primary display, the room's windows. A simplified model of the harbour was generated in addition to the redesigned control room supporting an evaluation of the design's influence on the visibility of the shipping lanes.

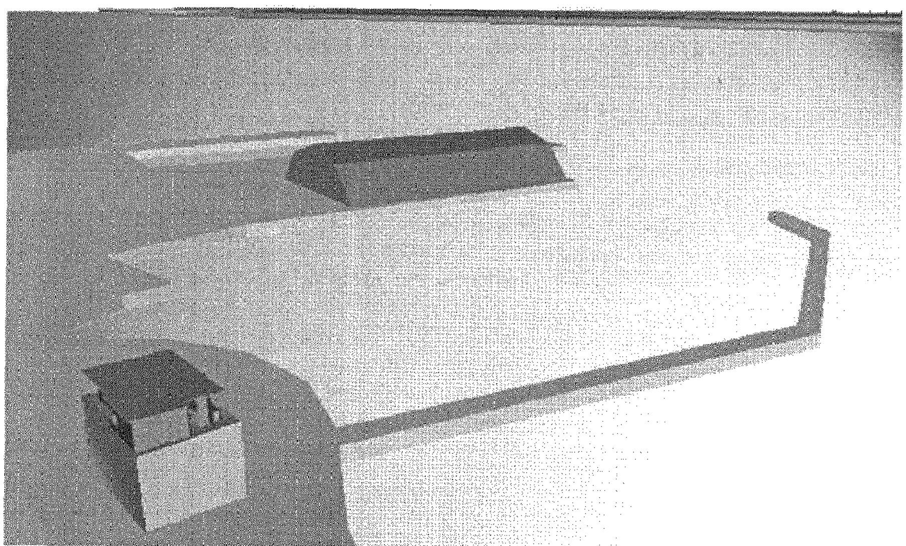

**Figure 2. JACK Model of a Harbour Control Room Including External View**

The utility of body modeling tools is not limited to design evaluation against human factors guidelines. Figure 3 illustrates a detailed model of a closed circuit television control room modelled and evaluated by CHS. Interactive control and animation of a human mannequin within this environment supported a standard analysis of fit, reach and vision within the proposed room. Techniques such as texture mapping and shadowing helped to quickly build a realistic representation of the environment. By visualising the environment, the model offered an accessible medium for the stakeholders to develop a common design concept. The model was used by representatives of the designers and the users to review the environment and interactively make changes to its proposed design. At the same time, the knock-on effects of these changes were assessed from a human factors perspective. This process led to the gradual evolution of the design as alternatives were prototyped and iterated.

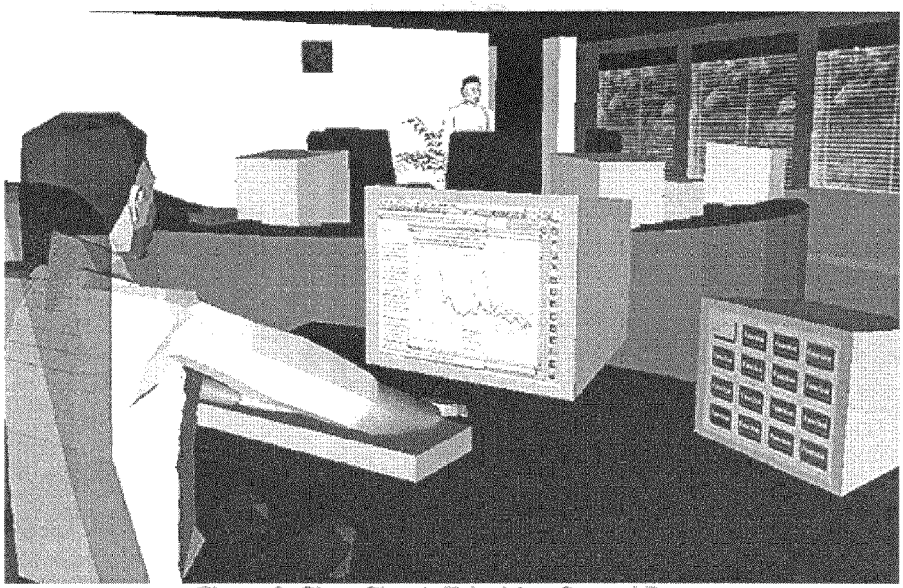
Figure 3. Close Circuit Television Control Room

## USER REQUIREMENTS FOR BODY MODELING TOOLS

The cases described illustrate real applications of body modeling as a tool to provide human factors input within the design process. Computer based body modeling is a relatively recent technique and there is considerable scope for improvement to the tools. The value of this technique has provided the motivation to work within the shortcomings of its supporting tools. There remain many reliability, usability and functionality issues relating to the tools applied within CHS which currently inhibit their wider use.

### Reliability

Workspace evaluation requires the body modeling tool to be consistent, stable and valid. The user needs to be confident in the tool's ability to repeatedly provide an accurate interactive model of the human and its environment. Human body models have tended to increase in complexity in order to provide a more accurate representation of the individual. However, the multiple degrees of freedom which characterise the joints of the human body place significant processing demands on the software simulation. When interactively manipulating a mannequin within a 3D model, these models must balance the constraints of the mannequin's skeleton with the constraints of the environment and the instructions of the tool's user. There is a risk that small variations in position and action will lead to a wide variation in mannequin response. This can reduce the apparent realism in movement of the human figure. In addition, these inconsistencies challenge the use of these tools for workspace evaluation which relies on a degree of repeatability before conclusions can be drawn concerning fit and reach. Furthermore, the increase in the number of calculations performed during simulation raises the risk of software failure. The effort invested in developing an environment and an associated evaluation procedure can be quickly lost in a software crash. The effect of this can be a loss of confidence in the tool leading to a more narrow application of the tool's advertised capabilities for future projects.

## USABILITY

The usability of these tools has been greatly enhanced by the improving cost to power ratio of computer hardware. It is now possible to display and interact with fully shaded 3D models. Past human modeling relied on wire frame representation of the environment which was often difficult to interpret. Despite these improvements, the overall usability of these tools tend to fall short of their potential. An apparent side effect of increased processing power has been an increase in the overt functionality of these tools. In some cases the user is faced with a range of functions, each requiring the definition of numerous obscure attributes before a mannequin behaviour can be implemented. Whilst increasing control over the simulated human is a positive goal, the manner of its implementation is critical. It should not be necessary to alter balance controls in order to manoeuvre a mannequin onto a seat. These tools need to automate fine control of the mannequin with the option of a manual override by the user at any point or level of detail.

Control within 3D virtual environments remains a difficult problem to solve. Most systems allow mouse control, modulated by holding down combinations of the mouse or keyboard keys to control movement in each axis. Other devices such as joysticks and space balls offer an alternative without offering a truly intuitive interface. 3D position sensors such as the polhemus system (Polhemus) allow the mannequin to mimic the limb movements of the user but remain an expensive and cumbersome solution. A further alternative is provided by an instrumented physical mannequin called the "Monkey" (Digital Image Design Inc.) which, when linked to the body modeling tool, allows direct manipulation of the human model.

Despite these control options, human body modeling remains a cumbersome tool. When evaluating a design, certain questions are asked such as, can the population reach control A?, or can the population see screen B? For these tools to reach their potential, they must provide answers to these questions with the minimum of effort on the part of the user. One approach to achieving this is to provide the mannequin with a working understanding of the environment. For example, it should know what a chair is and how to sit on it. It should know what a screen is for, how to turn it on and whether it is in a comfortable position. What is needed is for the computer to take on the labour intensive tasks of mannequin control to free up human effort to consider the information provided by the tool.

### Functionality

Whilst expanding functionality has been highlighted as a potential hindrance to usability, enhancement of the human body model could help to improve tool usability and user confidence, particularly where added complexity is hidden from the user. Continuing efforts to improve the reliability and consistency of these tools require the improvement of existing functions such as collision detection and the development of new functions such as a method of arbitrating between the numerous inputs to the model to achieve consistency in the mannequin's actions. All of these advances will be diminished if they are not implemented in way that is sensitive to the users' requirements.

Work to enhance the model of human performance and behaviour within synthetic environments is one area in which the human body model could be developed into a more powerful human factors tool. For example, current evaluations require the expert to make a judgement of the user's ability to operate in an environment for a prolonged period. By including and improving human behaviour and performance models for mannequins it may become possible to define operational scenarios to test variables such as temperature, fatigue and stress when considering a proposed layout. Models of attention and information processing capacity could be used to highlight features of a design which might lead to an insupportable load under situations of high activity or a likelihood of error during periods of low activity.

Although initially rejected by this discussion, the potential contribution of immersive interaction within the virtual body modeling environment may provide new insights to design once the technology has matured sufficiently. The ability to experience a proposed environment from the perspective of a 97th percentile maintenance technician or even through the eyes of a visually impaired operator has the potential to demonstrate the importance of accounting for variation, both human and situational, in design in a new and powerful way.

## CONCLUSION

Human body modeling provides the human factors engineer with a new tool which ties together the opportunities of computer aided design and the user centred techniques of prototyping and iterative design. It was stated at the start of this paper that "the task of the human factors engineer is to match the design of systems to the requirements and capabilities of their human users." It seems reasonable to expect this goal to be prominent in the design of the tools offered to support this process. Continued efforts to improve these tools along these lines should secure the place of this technology as an important tool for supporting a human factors input to design.

## INFORMATION LINKS

Alias Wavefront, Kinemation, http:/www.aw.sgi.com

British Technology Group, Sammie,
http:/lut.ac.uk/departments/cd/docs_dandt/staff/porter/sammie.html

Boeing, MDHMS, http:/boeing.com/

Boston Dynamics, Inc., DI-guy, http://www.bdi.com/html/di-guy.html

CSERIAC, COMBIMAN & Crew Chief, http://cseriac.udri.udayton.edu/products/

Deneb Robotics, Inc., ERGO, http://www.deneb.com/ products/ergo/ergo.html

Defence Evaluation and Research Agency, Centre for Human Sciences, http://www.dera.gov.uk/

Digital Image Design Inc., The Monkey, http://www.didi.com/

Fractal Design, Poser, http:/www.fractal.com/poser/poser.html

Genicom, Safework, http:/www.safework.com/index.html

HumanCAD, MannequinPRO, http:/www.humancad.com/

Mechanical Dynamics, Android, http://www.adams.com/mdi/product/modeling/modeling.htm

Musculographics, Inc., Musculographics, http://wwwmusculographics.com/

Polhemus, The Polhemus Sensor, http://www.polhemus.com/

Transom, JACK, http:/www.transom.com/